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Unmanned Aerial Vehicles for Maritime Patrol: Human Factors Issues

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ABSTRACT

This review of literature outlines the human factors issues associated with the operation of unmanned aerial vehicles (UAVs). In particular, consideration is given to how these issues might be relevant to the acquisition of highly autonomous, high altitude long endurance (HALE) UAVs for maritime patrol and response operations. In a highly automated UAV system, optimal mission performance will require the roles of the operator and the automated system to be complementary. Thus factors that may inhibit cooperation between the two are addressed and suggestions are made for the mitigation of potential problems. The discussion then turns to the design of the human-machine interface (HMI), providing information on established HMI design principles and issues relating to the separation of the operator from the aircraft. The final section covers the air traffic management procedures for the hand-over of control during flight, data link delays and their impact on team dynamics, the selection of crew members, and the delineation of roles for UAV crews.

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Operation of Unmanned Aerial Vehicles: Human Factors Issues

Executive Summary

Project AIR 7000 seeks to procure military systems to replace the maritime patrol and response capabilities currently provided by the AP-3C Orion fleet of aircraft. The replacement fleet is likely to include both manned and unmanned aircraft. The Air Operations Division (AOD) of the Defence Science and Technology Organisation (DSTO) has been tasked to provide support to Project AIR 7000. This support will include an assessment of the impact of operating high altitude long endurance (HALE) unmanned aerial vehicles (UAVs) in maritime patrol scenarios. The review of literature in this report provides insight into a research area 4.4.1 *Human Machine Interfaces* in the project science and technology plan. The aim of this report was to identify the areas in which there is a firm understanding of the human aspects of control of UAVs and where there are issues requiring deeper examination.

The UAV human factors discussed here have been divided into three broad areas: automation, the human-machine interface (HMI) and air traffic management and crewing. The UAV selected for a maritime patrol and surveillance role is likely to be highly automated, thus various issues relating to operators' interaction with automated UAV systems are raised and suggestions for improving this interaction are given. The HMI section addresses a variety of new challenges to aviation HMI design that result from the separation of crew from the aircraft and outlines some traditional display design factors that may help to alleviate problems caused by this separation. The final section addresses the air traffic management procedures for the hand-over of control during long flights, communications processes, data link delays and crewing. In terms of crewing, the report addresses the delineation of roles for the crews of UAV systems and the type of qualifications necessary to operate UAVs successfully.

This paper does not directly address any of the milestones to be completed through AOD support to AIR 7000, however, the following discussion may inform a number of these milestones. Issues are raised that should be considered during analysis of unmanned systems alternatives, detailing the differences between each candidate system (3.3.5.2), and the air traffic management and crewing section provides information that will be useful to the workforce description for AIR 7000 (3.3.1.1). Additionally, information provided here may be taken into account during design of experiments for milestones relating to conducting constructive experiments for developing and refining the concepts of operation (CONOPS) for the AIR 7000 Capability (3.1.2.2, 3.1.2.3), and crew-in-the-loop experiments for optimising the performance of the operator and analyst community on the AIR 7000 Capability (3.1.2.5).

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Glossary

AOD	Air Operations Division
ATC	Air Traffic Control
AVO	Air Vehicle Operator
BAMS	Broad Area Maritime Surveillance
CCO	Command & Control Operator
CONOPS	Concept of Operations
DEMPC	Data Exploitation, Mission Planning, & Communications
DSTO	Defence Science and Technology Organisation
FOV	Field of View
GCE	Ground Control Element
GH	Global Hawk
HALE	High Altitude Long Endurance
HMI	Human-Machine Interface
JASS	Job Assessment Software System
LRE	Launch & Recovery Element
MC	Mission Commander
MCE	Mission Control Element
MIIRO	Multi-modal Immersive Intelligent Interface for Remote Operation
MP	Mission Planner
PIP	Picture-in-Picture presentation
SA	Situational Awareness
SAR	Synthetic Aperture Radar
SCS	SmartCam3D System
SO	Sensor Operator
UAV	Unmanned/Uninhabited Aerial Vehicle
UCAV	Unmanned/Uninhabited Combat Aerial Vehicle
UGV	Unmanned/Uninhabited Ground Vehicle
USAF	United States Air Force
USN	United States Navy

1. Introduction

Project AIR 7000 seeks to procure military systems to undertake maritime patrol and response capabilities currently performed by the AP-3C Orion fleet of aircraft. The replacement fleet is likely to include both manned and unmanned aircraft. The Air Operations Division (AOD) of the Defence Science and Technology Organisation (DSTO) has been tasked to provide support to Project AIR 7000. This support will include an assessment of the impact of operating high altitude long endurance (HALE) unmanned aerial vehicles (UAVs) in maritime patrol scenarios. The review of literature in this report represents the initiation of AOD support to human factors aspects of the Air 7000 Phase 1 Technical Risk Assessment. This report was conceived as an initial scoping exercise, aimed at identifying where there is firm understanding about human aspects of control of UAVs and where there are issues requiring deeper examination.

The UAV human factors discussed here have been divided into three broad areas: *automation*, *the human-machine interface (HMI)* and *air traffic management and crewing*. The UAV selected for a maritime patrol and surveillance role is likely to be highly automated, thus various issues relating to operators' interaction with automated UAV systems are raised and suggestions for improving this interaction are given. The HMI section addresses a variety of new challenges to aviation HMI design that result from the separation of crew from the aircraft and outlines some traditional display design factors that may help to alleviate problems caused by this separation. The final section addresses the air traffic management procedures for the hand-over of control during long flights, communications processes, data link delays and crewing. In terms of crewing, the report addresses the delineation of roles for the crews of UAV systems and the type of qualifications necessary to operate UAVs successfully.

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2. Automation

The UAV selected as part of the AIR 7000 project is likely to be highly automated in terms of flight control. Operators will monitor flight and system performance from a station on the ground. Optimal flight performance will require that the operators be aware of and

understand the activities of the automated system, and that the actions of operators and the automated system complement rather than compete with one another. Achieving this will require an examination of the issues that will affect the performance of the operator, the automated system and the collaboration between the two. The following discussion addresses these issues and includes suggestions aimed at improving flight performance by increasing cooperation between the human operator and automated system.

2.1 Overview of automation

Automated functions have been defined as those functions performed by a machine that were historically, and to a considerable extent still are, performed by human operators (Parasuraman & Riley, 1997). For example, while the pilots of many aircraft still manually control pitch, roll, yaw and acceleration during the take-off phase of flight, it is becoming increasingly common for control of these parameters to be automated. In highly automated aircraft, the pilot may initiate landing by pressing a button, or sequence of buttons, and then switch to a monitoring and supervisory role while the automated system performs the function. Automating various functions has the potential to allow the reallocation of the pilot's physical and cognitive resources to higher-level operations, and to improve the functioning of the pilot-aircraft system. However, optimal system performance requires that the strengths and limitations of the human operator and the potential shortcomings of the automated system be taken into account when deciding which functions to automate, to what level, and in what form.

There are two general arguments for automating a function. The first is to eliminate human error on high risk operations and the second is to reduce operator workload, to avoid cognitive overload and to allow the reallocation of the operator's physical and cognitive resources to other areas (Sarter, Woods, & Billings, 1997). In relation to the first argument, the automation of procedures that, when performed by operators, have a high risk of human error has been found to reduce the rate of accidents. For example, two very high-risk segments of flight for both manned and unmanned aircraft are the take-off and landing phases (Williams, 2004). Automating these phases so that the pilot (or operator) prompts the system to begin the take-off or landing sequence and then monitors the progress of the system has significantly reduced the rate of accidents during these phases of flight (McCarley & Wickens, 2005). Removing the pilot's responsibility to control the aircraft manually during these phases does not completely remove the risk of human error, as human error is still possible during mission planning and maintenance operations.

In addition, with automation comes the risk of automation failure. This issue is even more problematic when the high level of automation prohibits or increases the difficulty of overriding the system (McCarley & Wickens, 2005) or when automation is accompanied by a reduction in the operator's ability to detect the failure. Increases in automation are usually accompanied by a decrease in system transparency. The lack of transparency can result in a reduction in operator situational awareness (SA) as the operator may misinterpret or be unaware of the actions taken by the system and thus may develop an inaccurate or incomplete mental model of the flight environment or tactical situation (Wickens, 2000). This reduction in SA is likely to reduce the operator's ability to detect

system failures (Olson, 2001). The lack of system transparency can also affect the operator's trust in the system. The operator may lose trust and rely less on the automated functions, and thus not benefit from them to the same degree. Or the operator's trust may inflate when such an increase in trust is unfounded, causing a reduction in the level of monitoring and a decrease in the likelihood of detecting and responding to system failures (Parasuraman, Molloy, Mouloua & Hilburn, 1996). Riley (1996) conducted a series of studies aimed at determining the factors influencing an operator's reliance on automation. The findings suggested that reliance on automation is influenced by an operator's confidence in his or her own abilities, the level of trust placed in the automated system, operator fatigue, and perceived risk. These factors are, in turn, influenced by other factors, for example, perceived risk may be influenced by actual risk, trust in automation may be influenced by the accuracy of the machine, and confidence may be influenced by task complexity. In summary, the first goal of automation is satisfied to some extent in that automation can be used to reduce human error on high risk operations. However, automating functions does not eliminate human input entirely, and thus the chance of human error still exists. In addition, increases in automation introduce the problem of automation failure, and the effect of over-trust or mistrust of the automated system on operator performance.

In relation to the second argument, regarding workload, automation of flight control has been found to free the attentional resources of pilots and allow the reallocation of these resources to higher-level operations and decisions (Dixon, Wickens, & Chang, 2003). However, the degree to which this can be achieved depends on the design of the system and the requirements of the mission. There is evidence to suggest that automation can actually increase operator workload and reduce SA (Ruff, Narayanan & Draper, 2002). Although automation does relieve the operator of some responsibilities, with higher levels of automation, the role of aircraft pilots has been progressively steered away from one that humans are inherently suited to, toward one that involves tasks on which humans generally perform poorly. Manually controlled systems often require aircraft pilots to perform a range of tasks that involve the frequent shifting of attention, interpretation of ambiguous or incomplete information, and drawing from a range of information sources and from experience to find a *best fit* solution to problems under time pressure, tasks on which humans are likely to outperform computers. Highly automated systems often require that aircraft pilots take on a supervisory role, monitoring the system and mission and remaining alert over lengthy time periods, tasks on which humans are known to perform poorly (Parasuraman, Molloy, & Singh, 1993). Automation has the potential to provide a range of benefits. However, realising this potential will require an investigation of which tasks are most appropriate to automate and to what degree (McCarley & Wickens, 2005).

2.2 Levels of automation

Levels of automation can be said to vary along two separate continuums, as shown in Figure 1. One continuum involves information processing, decision making and problem solving, and the other involves the control of basic flight, that is, pitch, roll, yaw, speed and altitude. Systems that approach the higher ends of these continuums, that is, systems that decide and act with limited operator input or that independently monitor and adjust

basic flight parameters, have the potential to free up the cognitive and sensorimotor resources of the operator.

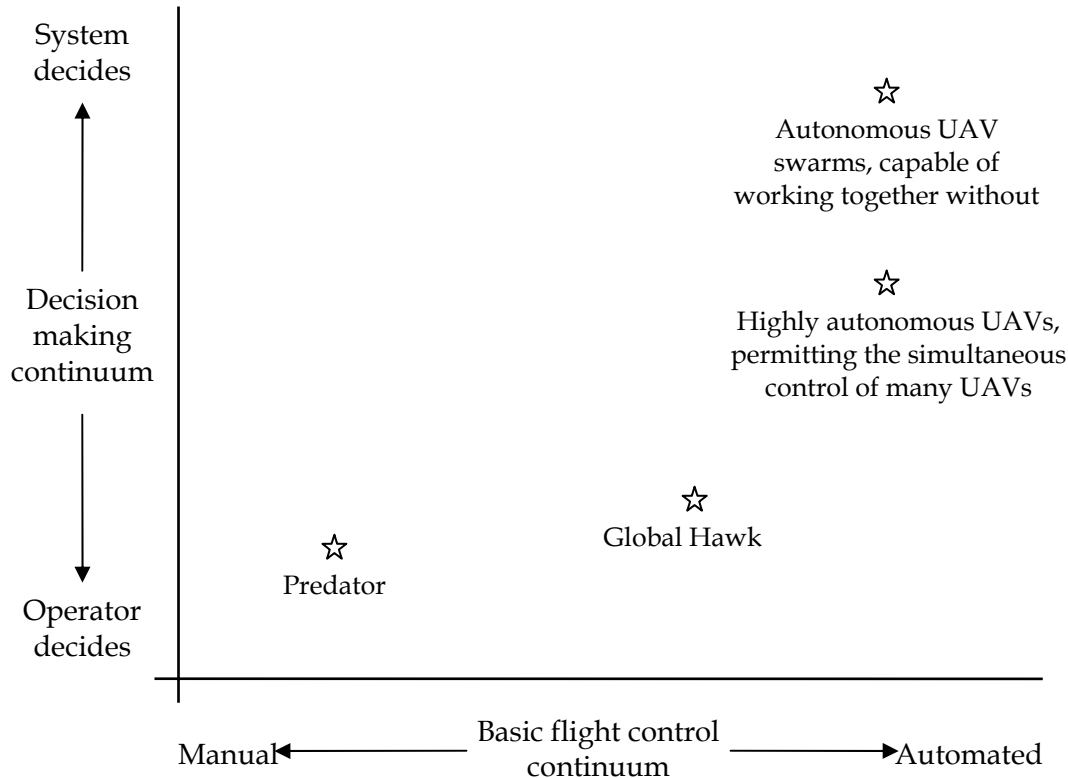


Figure 1. The automation levels of various UAVs. The Y-axis represents automation along a continuum of information processing and the X-axis represents automation along a continuum of basic flight control.

For information processing, decision making and problem solving, two general categories of automation are described in the literature (Ruff, et al., 2002): management-by-consent and management-by-exception. Management-by-consent refers to an automated system that proposes a form of action, but that does not perform the action until it is consented to by the operator. *Management-by-exception* refers to the situation in which the automated system acts without direction from the operator, but can be interrupted by explicit instructions from the operator. In addition, automation may be complete, that is, the system may make all decisions and instigate all actions without involving the operator in the decision making process, or automation may be absent, that is, all decisions may be made by the operator. Parasuraman, Sheridan and Wickens (2000) suggested that levels of automated decision making lie along a continuum from completely operator controlled to completely automated. Table 1 outlines the automation continuum suggested by Parasuraman, et al., showing how it fits into the automation categories previously mentioned. The table shows that a number of levels of automation fall into the categories of management-by-consent and complete automation. The levels of automation vary in

transparency, with the operator having greater visibility of the internal processes of the system, and thus greater SA, when the system is less automated (Ruff, et al., 2002).

Table 1. The automation continuum proposed by Parasuraman, et al. (2000)

Automation continuum	Management strategy	Description of automation according to Parasuraman, et al. (2000)
10	Complete automation	The automated system makes all decisions and acts autonomously.
9	Complete automation	The automated system decides whether to inform the human operator of its decisions and actions.
8	Complete automation	The automated system informs the human operator of decisions and actions at the operator's request.
7	Complete automation	The system executes actions automatically, but keeps the human informed.
6	Management-by-exception	The human is informed of the system's intentions and is given the opportunity to veto actions within a set time frame.
5	Management-by-consent	The automated system evaluates the information and provides a suggested course of action, which will take place only after the human's consent.
4	Management-by-consent	The automated system suggests a course of action and the operator decides whether to accept or reject this suggestion.
3	Management-by-consent	The automated system provides a small set of alternatives, from which the human chooses a preferred course of action.
2	Management-by-consent	The automated system offers an extensive set of alternative decisions or actions, from which the operator selects a preferred course of action.
1	Operator-managed	The automated system provides no assistance. The human operator makes all decisions and takes all actions.

The second continuum along which the level of automation varies is one of manual control. This is explained by the following example. The Predator UAV is under the manual control of the operators in a ground control station (the layout of a Predator ground control station is provided in Figure 2a). Images of the mission plan and flight environment are presented to the pilots on a screen and they control the flight of the aircraft for the entire mission, including take-off and landing. The interface between the operators and the aircraft is similar to that in manned aircraft, featuring a stick, throttle and pedals for each pilot. In contrast, flight of the Global Hawk UAV is highly automated (the layout of the ground control station is provided in Figure 2b). For Global Hawk, the

take-off and landing phases of flight are automated, and the waypoints for the entire mission are specified during mission planning. The automated system monitors and modifies pitch, roll, yaw, speed and altitude to reach the specified waypoints. The interface between the operators and the aircraft consists of monitors displaying the mission plan and sensor imagery, and a mouse and keyboard through which the operator can modify the flight plan and re-task the sensors during flight. Both levels of automation have their benefits and associated pitfalls. The high level of automation of the Global Hawk system can help to alleviate the communications delays that can occur with full manual control (Mouloua, Gilson, Daskarolis-Kring, Kring, & Hancock, 2001) and can help to avoid the continuously high level of cognitive workload that is experienced by Predator pilots (McCarley & Wickens, 2005). High levels of automation can, however, prevent the operator from rapidly intervening to override automation when necessary (McCarley & Wickens).

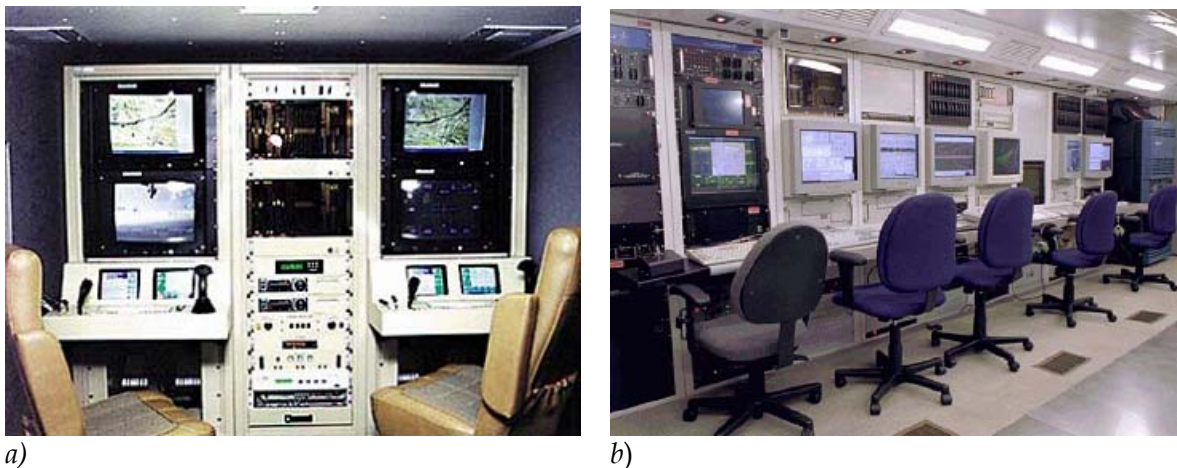


Figure 2. a) The setup of a Predator ground control station, and b) the setup of a Global Hawk ground control station

Figure 1 shows the relative positions of the Predator and Global Hawk UAVs along the two continuums of automation. The figure shows that Global Hawk is much more automated than Predator in terms of the control of basic flight parameters. Both UAVs are positioned fairly low along the decision making continuum, showing that the operators of both systems are still largely responsible for deciding upon and initiating a course of action. Future aircraft are likely to be positioned more towards the higher ends of both continuums. With this increase in aircraft automation is likely to come an increase in capability. High levels of automation will permit the simultaneous control of a number of UAVs by one operator. With technological advances, high levels of automation involving intelligent agents may also allow swarms of UAVs to work together completely autonomously to achieve mission goals. While it is clear that automated systems have the potential to provide a range of benefits, it is also clear that these benefits will only be realised if the integration of automation involves a thorough investigation of potential human factors issues. The investigation should determine the strengths and weaknesses of the human operators and the strengths and weaknesses of the automated system, and all

attempts should be made to ensure that the two entities coordinate such that the benefits of each are maximised and the costs of each minimised.

2.3 The automation level of the maritime UAV selected for AIR 7000

Phase 1 of the AIR 7000 project is aimed at selecting a UAV suitable for the reconnaissance and surveillance of Australia's coastline. An option being considered as part of the AIR 7000 project is to collaborate with the US Navy (USN) on their Broad Area Maritime Surveillance (BAMS) program to select this UAV. The BAMS Operational Requirements Document (BAMS Program Office, 2004) suggests that the selected UAV would be more similar to Global Hawk, in terms of automation, than to Predator. A level of UAV autonomy has not yet been selected for AIR 7000 and will depend on whether collaboration with the USN is agreed on, and the costs and benefits (both financially and in terms of system performance) of various levels and types of automation. The BAMS document states that the UAV system should be capable of autonomously conducting all parts of a mission, that is, takeoff and landing, navigation, on-station loitering, and maritime intelligence, surveillance and reconnaissance. However, it is expected that the UAV controllers will have the ability to direct the UAV and sensors, to deviate from the programmed course, and to loiter or track a specific element detected during surveillance.

2.4 Global Hawk mission planning

Highly automated UAV systems such as Global Hawk require complicated and lengthy mission planning. As the automation level of the selected UAV would be similar to that of Global Hawk, it is likely that mission planning and in-flight retasking will also be conceptually similar. The mission planning process for Global Hawk can be expensive as missions can take up to nine months to plan. The process is complex and involves the creation and validation of a navigational route and tactical plan based on the data collection requirements and target priorities (United States Navy, 2005). It also involves the incorporation of a number of contingency plans that will allow the safe, predictable operation of the UAV in the event of equipment failure or loss of communications with the ground control station. Mission planners must consider the capabilities and limitations of the aircraft, sensor performance, communication capabilities, altitude and the associated detection ranges and image quality, track spacing, ground speed and loitering time. They must also consider factors relating to the operational environment, such as the likely weather conditions, the environmental conditions that may affect sensor performance, the search area size, the search area location, the location of friendly forces, the capabilities of friendly forces, the location of known enemy forces and threats, and the capabilities of these threats (United States Navy). The Global Hawk system does not permit waypoints to be added during flight, and therefore a method often employed is to include a large number of waypoints in the mission plan, densely covering all possible areas of interest with the understanding that not all of the waypoints will be reached. This provides controllers with greater flexibility to modify the flight path during the mission. This flexibility is important, as it is difficult to anticipate all of the variables during mission planning that will be present during its conduct.

2.5 The role of the Global Hawk automated system

During flight, the Global Hawk autopilot is completely responsible for the takeoff and landing phases. It is also responsible for ensuring that airspeed and altitude meet the specifications defined during mission planning and for directing the aircraft towards the designated waypoint.

2.6 The role of the Global Hawk operators

During the mission, the crew's task is to monitor the health and status of the aircraft, to process and disseminate information collected via the sensors, to retask the sensors and to update the mission plan in accordance with new information (United States Air Force/Australian Department of Defence, 2001). After arriving at a search area, the sensor operators generally use a broad-area search sensor to detect any entities present in the area. Higher resolution imagery is then collected and used to classify and identify these entities. The sensor operators collaborate to determine whether there are specific areas that need to be revisited and communicate their recommendations to the mission commander. The Global Hawk mission concludes when mission objectives have been achieved, targets have been imaged and evaluated, collection products have been disseminated to the requesting agencies, and the flight has been successfully recovered (United States Navy, 2005).

2.7 Human factors issues for Global Hawk

The high automation level of Global Hawk is beneficial in that it reduces the rate of human error, particularly during the takeoff and landing segments of flight (Williams, 2004); however, some issues have arisen as a result of this increase in automation. Williams identified automation as being central to many of the human factors issues that are of concern in the case of the Global Hawk UAV. He suggested that Global Hawk operators find it difficult to monitor the automated system closely over extended periods. This can cause a reduction in SA and a decreased ability to deal with system faults and failures when they occur. In addition, in highly automated systems, an operator's visual scan methods are likely to be dictated by his or her expectations. That is, the operator is likely to monitor only some cockpit instruments to check that the system is performing as expected (Sarter & Woods, 1995). This may increase the difficulty of detecting unexpected events or unanticipated system failures. Research should be directed at improving the long term monitoring skills of operators or modifying tasks to reduce the level of monitoring, and make tasks less mundane.

The performance and reliability of the automated system can also affect the way an operator responds to the system. It is unlikely that an automated system will ever be perfectly reliable (Ruff, et al., 2002). It is therefore important to consider how performance can be optimised under such imperfect conditions. Operator performance will be optimal if the operator has a realistic understanding of the reliability of the automated system and the types of system failures that are likely to occur. It is therefore important to consider the best way of alerting operators to system failures. Operators may also benefit from being trained to respond quickly and appropriately to generic system faults.

Automation feedback is often inadequate (Olson, 2001). Autopilot operations should be transparent (Sarter, et al., 1997) and feedback should be sufficient in amount, type and salience to ensure that the operator has all of the information required to perform the job efficiently. The methods of changing modes and performing functions should be intuitive and the pilot should always be aware of the current mode or state, understand its implications, and be able to predict future states of automation (Sarter & Woods, 1995).

The type and quantity of information provided can effect the way the mission is run considerably. It can be difficult for mission planners to foresee all possible conditions that may arise during flight, so granting the operator access to all needed information can be difficult. It can also be difficult to organise the information so that the pilot has adequate access to it, but is not overloaded. It may be appropriate to provide access to hierarchies of information through which operators can navigate to find the information they require; however, it is important to ensure that this navigation process does not consume excessive time or mental effort, particularly when the operator is required to act under time pressure. Mission planning also involves the creation of contingency plans. These plans are essentially scripts outlining the actions that will be taken by the Global Hawk system in response to certain events, for example, a loss of ground-to-air communications. To avoid confusion, the behaviour of the UAV under these conditions should be predictable and communicated clearly to Air Traffic Control (ATC) and the UAV operators (McCarley & Wickens, 2005). It may be necessary to include software that is designed to check for hazardous contingency plans and other mistakes made during mission planning. Research aimed at improving the efficiency and effectiveness of this type of software may help to reduce aircraft attrition.

2.8 Summary

Aircraft automation can help to circumvent human error on high risk tasks, reduce operator workload and permit the reallocation of UAV operators' physical and cognitive resources to higher level functions. However, for automation to be most useful, a number of human issues need to be considered and accounted for. It is important to be aware that automating various functions does not eliminate human input entirely. There is still the potential for human error during mission planning, system design and maintenance operations. Also, automated systems do not always perform perfectly. System designers and operator trainers therefore need to consider the effect of imperfect automation on operator performance. Levels of automation can be said to vary along two continuums: one involving information processing, decision making and problem solving, and the other involving basic flight control. Systems that approach the higher ends of these continuums, that is, systems that decide and act with limited operator input or that independently monitor and adjust basic flight parameters, have the potential to free up the cognitive and sensorimotor resources of the operator. The result of automation will be optimal if the operator's resources can be reallocated to roles that humans inherently perform well, such as decision making, rather than roles they tend to perform poorly, such as long-term system monitoring.

The UAV selected for phase one of the AIR 7000 project is likely to be highly automated and to resemble Global Hawk in terms of automated decision making and flight control. Therefore, the human factors issues that have been found to be of concern for Global Hawk are also likely to be of concern for the UAV selected. These include costs due to the length and complexity of mission planning, human error during mission planning, the difficulty of anticipating all potential environmental and flight issues months in advance, and whether software can be incorporated to check for errors made during mission planning and hazardous contingency plans. During flight, Global Hawk operators are also faced with the challenge of maintaining adequate SA of the flight environment, flight climate and system performance over long periods, a task made more difficult by inadequate automation feedback. For flight performance to be optimal, the operator and the automated system must behave in ways that complement, rather than in compete with one another. To this end, it is important to consider the issues that can influence the performance of the human operator, the automated system, and of the collaboration between the two.

3. The Human-Machine Interface

Potential problems relating to the HMI need be considered. This section summarises major HMI issues that are pertinent to the operation of long endurance, highly autonomous UAVs such as the Global Hawk or Mariner. Where possible, potential improvements to HMI design that have been raised in the UAV literature are also discussed.

3.1 Display principles

By definition, UAV operators and the UAVs they control are not co-located in space. This raises a number of human factors issues that are new to aviation HMI design. In addition to these UAV-specific issues, adherence to some of the traditional principles of interface design is essential.

Mission control element (MCE) operators for the 2001 deployment of Global Hawk in Australia rated status displays and controls in the MCE as consistently unacceptable (see Table 2). Several areas were identified as problematic including the physical arrangement of the displays (too far apart), the unnecessarily complicated retasking processes, and difficult-to-read displays (due to the fonts and colours that were used). Such problems suggest that some standard design guidelines have been overlooked.

Table 2. MCE Operators' responses to Human Factors Questionnaire¹

Question	Median Rating
Rate the mental effort workload during task completion with the Global Hawk (GH) UAV system.	Poor to Acceptable
Rate the physical workload during task completion with the GH UAV system.	Acceptable
Rate the time pressure during task completion with the GH UAV system.	Acceptable
Rate the work backlog during task completion with the GH UAV system.	Acceptable
Rate the adequacy of the physical arrangement of the workspaces in the MCE.	Unacceptable to Poor
Rate the lighting in the MCE facility.	Acceptable
Rate the heating and cooling facilities in the MCE.	Poor to Acceptable
Rate the level of noise in the MCE.	Acceptable
Rate the freedom of motion within the MCE	Poor
Rate the utility of the status displays and indicators in the MCE.	Unacceptable
Rate the utility of the controls and menus in the MCE.	Unacceptable
Rate the ease of access to displays, indicators, and controls in the MCE	Unacceptable

Wickens and Hollands (2000) describe seven critical principles of aviation display design, developed through an understanding of the psychology of information processing:

1. *Principle of information need:*
Information that is required more frequently should be displayed in the most accessible locations;
2. *Principle of legibility:*
Displays must be legible to be useful. That is, large enough and with adequate contrast, brightness, illumination, volume (for auditory displays) etc.;
3. *Principle of display integration/proximity compatibility principle:*
Information sources that need to be integrated or compared should be positioned in close physical proximity on the display;
4. *Principle of pictorial realism:*
The display should be a pictorial representation of the information that it represents;

¹ Taken from Global Hawk Australian Demonstration Assessment Report (USAF/Australian Dept. of Defence, 2001, section 3, pp.44). Possible responses were *Unacceptable*, *Poor*, *Adequate*, *Good*, or *Excellent*.

5. *Principle of the moving part:*

The moving element on a display should correspond to the moving element in the operator's mental model;

6. *Principle of predictive aiding:*

Predictive information regarding future aircraft state is valuable (as long as it is accurate and easily understood), and;

7. *Principle of discriminability:*

A display element in a certain context should never look (or sound) similar to another element that could occur in the same display context.²

The MCE displays used in the Global Hawk Australian demonstration of 2001 appear to have breached several of these principles. For example, the difficulty of reading displays stems from a violation of the principle of legibility; the spread of the displays does not appear to address the principle of information need or the proximity compatibility principle, and; the difficulty in retasking may be due to a lack of pictorial realism (the process of retasking is a complex text-based process, rather than just pointing and clicking on a target). These instances demonstrate that there are some very basic design issues with information presentation that need to be considered when investigating the utility of UAV HMIs. It is important to consider principles, such as those outlined by Wickens and Hollands (2000), in conjunction with the requirements set out in the CONOPS for the system, and an effort must be made to satisfy both sets of criteria. Also, any influence that might be had on redesign should take into account any foreseeable future implementations of the system.

Alerts are another aspect of the HMI that should be carefully considered. Alerts – visual, auditory, or otherwise – should signal to operators that there is a situation that requires their attention, but with minimal disruption to work (Wickens, 2003). It is important for alerts to be easily interpreted; however, this criterion did not appear to be satisfied when Global Hawk was deployed to Australia in 2001. On this occasion, MCE operators rated their ability to use the HMI both to detect and to identify abnormal conditions on the aircraft as *poor* (USAF/Australian Dept. of Defence, 2001). A criterion for how serious a situation becomes before an alert is displayed must be set. The level to which this is set should minimise the risk of failing to alert the operator to a serious condition, while ensuring that the alerts do not become an annoyance (Wickens, 2003). Frequent nuisance alarms can lead to distrust of the alert system and can result in operators ignoring true alarms (Pritchett, 2001). Making the raw data for an alarm decision accessible to operators can help to reduce distrust, and is an important consideration, given the increasing use of data fusion associated with the change to network-centric operations (Pritchett).

The manual controls are the operators' means of interacting with the software interface, and have serious implications for the safety of the system. For example, due to the assignment of menu selections to function keys on the Predator aircraft, the sequence of key presses required to control the lights was almost identical to the sequence for cutting

² This is a summary of the principles that are outlined in Wickens (2003). See Wickens and Hollands (2000) or Wickens (2003) for more detail and examples of the critical design principles.

off the engine, and hence offered the possibility of confusion with catastrophic consequence (Williams, 2004).

3.2 Remote operation: Sensory isolation of the operator

An examination of UAV literature reveals that one of the most prominent HMI issues is that of the sensory isolation of the operators (and other crew) due to their physical separation from the aircraft. Pilots and crew in manned aircraft have access to an abundance of multisensory information, aiding their understanding of the status of their aircraft in the environment (Draper, Ruff, Repperger, & Lu, 2000). Such information includes ambient visual input, and kinaesthetic³, vestibular⁴ and auditory information (McCarley & Wickens, 2005), and can provide pilots with cues to the speed of travel, banking angle, aircraft tilt, the air, ground and sea elements in the vicinity, weather conditions, and aircraft health and status. UAV operators can access a lot of this information via their instruments and displays, however monitoring these instruments would seem to be a more arduous and ill-suited method of building SA of the aircraft status and flight environment than to absorb this information in the way pilots of manned aircraft do. UAV operators often receive visual information from sensors onboard the UAV via data link; however, the imagery collected is limited in terms of range and quality (McCarley & Wickens). In addition, UAV operators do not have access to the vestibular cues that pilots of manned aircraft use to gain an understanding of the orientation of the aircraft, or the kinaesthetic cues pilots of manned aircraft use to gain an understanding of turbulence, weather conditions, aircraft movement and gravitational forces. Therefore, in cases of sudden wind turbulence where the pilot of a manned aircraft is likely to detect the change immediately through a combination of cues including vestibular sensations, noise, and rough handling of the aircraft, an operator of a highly automated UAV system may only become aware of turbulence upon noticing perturbation of the delayed video imagery transmitted from UAV-mounted cameras (Draper, Ruff, et al., 2000). The paucity of cues available to the UAV operator could result in a failure to detect or correctly diagnose the problem, and if the turbulence is severe enough, this could jeopardise the safe and effective control of the vehicle (Draper, Ruff, et al.). MCE operators for the 2001 deployment of the Global Hawk rated their ability to detect and diagnose abnormal conditions on the UAV via the human-computer interface as poor (USAF/Australian Dept. of Defence, 2001). In 2002 one of the US Air Force Global Hawks returning from a mission in support of Operation Enduring Freedom crashed after departing from controlled flight when part of the rudder mechanism failed (Small, 2003). Arguably, if the failure had occurred on a manned aircraft, various forms of sensory feedback would have alerted the pilot to the problem immediately, and there may have been time to diagnose the problem and recover the aircraft.

Given the dearth of multisensory cues available to the operators of remote vehicles, it has been suggested that the installation of multisensory interfaces may be beneficial (Wickens

³ The term, kinaesthetic, refers to the sensory experience of bodily position, weight and body movement that is mediated by tactile sensors in muscles, tendons and joints.

⁴ The term, vestibular, refers to the sense of balance and physical equilibrium that is mediated by structures in the inner ear.

& Hollands, 2000). Use of multisensory displays is not a new concept in aviation. For example, the use of augmented force feedback to mimic forces on the air surfaces of manned aircraft with fly-by-wire controls has long been established (McCarley & Wickens, 2005). It has been hypothesized that such interfaces may help to alleviate the high workload that can be experienced by an operator when a particular sensory mode is swamped with information (e.g., vision in cases where video footage, textual data, and maps are the prime sources of information, and audition in high noise environments; Calhoun, Draper, Ruff, & Fontejon, 2002). This hypothesis is based on Multiple Resource Theory, which supposes that different sensory modalities draw from different attentional resources (Calhoun et al., 2002; Wickens, 2002).

A number of studies have investigated the utility of multisensory displays for control of UAVs. These studies have been conducted in simulated UAV control stations for UAVs that are controlled manually in the stick and throttle style. The sensory cues examined include tactile feedback, such as application of vibration on the wrists, forearms, or control stick (Calhoun, Fontejon, Draper, Ruff, & Guilfoos, 2004; Draper, Ruff, et al., 2000); force feedback on the control stick (Gunn et al., 2002; Lam, Boschloo, Mulder, van Paassen, & van der Helm, 2004), cockpit environmental noise (Tvaryanas, Thompson, & Constable, 2005), and spatial audio cueing (Gunn et al.)⁵. The US Air Force Research Laboratory is also involved with the design and evaluation of IA Tech's multimodal immersive intelligent interface for remote operation (MIIRO), represented in Figure 3. MIIRO is utilised in planning and controlling missions for remotely operated vehicles and aims to reduce work and information overload in a number of ways including providing a partially immersive environment that "induces a sense of presence in the engagement area" (Wilson, 2002, pp. 57).

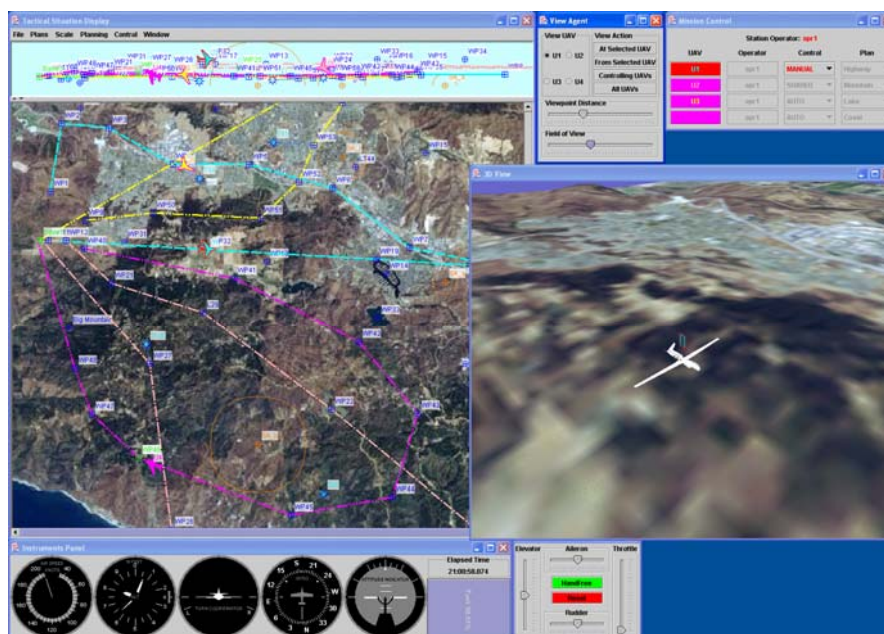


Figure 3. MIIRO: A multi-modal intelligent interface for remote operation

⁵ See Appendix A (Annotated Bibliography) for a description of each of these studies.

While the evidence provided by initial studies of multisensory interfaces suggests that they could be used to improve the performance of UAV operators, further investigation is required. The implications of sensory isolation for control of highly autonomous vehicles as opposed to manually controlled vehicles are not clear, and any interactions of interface type with level of experience of the operator are not yet known. Questions to answer in future study of this area might include the following:

1. Is providing multisensory cues as effective in a situation where the operator has less control over the aircraft (i.e., highly autonomous UAVs)?
2. Does a rated pilot benefit more from these cues than a non-pilot because of previous experience in manned aircraft? (Tvaryanas et al., 2005)
3. Does mimicking cues that would be present in a manned aircraft (such as ambient noise) benefit operators, or is the main benefit to be gained simply from making more effective use of attentional resources? (Draper, Ruff, et al., 2000)

3.3 Data links and sensor imagery

With the trend for the transition of defence forces to network-centric operations, the issue of data link delays and dropouts is becoming increasingly important. The occurrence of data link delays and dropouts are of particular concern for UAV flight due to their potential to interfere with control of the aircraft (Gawron, 1998; Mouloua, Gilson, Daskarolis-Kring, et al., 2001). These issues may be less of a concern when operations employ the use of highly autonomous UAVs with pre-programmed flight plans rather than manually controlled UAVs (Mouloua, Gilson, Daskarolis-Kring, et al.; Mouloua, Gilson, & Hancock, 2003); however, there is still potential for disruption to the operation of aircraft, for example, in situations where operators need to intervene with the automated flight and navigate to waypoints. During the 2001 deployment of the Global Hawk, it was noted that “system dropouts of sensors and computers in the MCE played havoc with the ability to get information on time”, and “generally speaking, the sensors were off line more than online” (USAF/Australian Dept. of Defence, 2001, Annex E, pp. 8).

The bandwidth and latency limitations of the data links that transmit imagery from the onboard sensors to the image quality control workstation mean that the quality and timeliness of the images received is often poor (McCarley & Wickens, 2005; van Erp, 2000). Environmental conditions and a highly cluttered visual scene can also make images difficult to interpret (Calhoun, Draper, Abernathy, Patzek, & Delgado, 2005). Van Erp has suggested that the problems resulting from the constraints of the data links may be circumvented by transmitting information only if it is task critical. Van Erp also discussed image parameters that can be critical in control of unmanned ground vehicles (UGVs) including field size, magnification factor, use of colour, update rate, spatial resolution, monoscopic/stereoscopic viewing, viewing direction, and placement and aiming. Similarly, it would be appropriate to determine what information is critical for control of UAVs and to assess whether data link capacity is being used in an efficient manner.

Another approach to overcoming problems with sensor image quality is to use augmented graphics displays. Such displays provide additional information to help the operator cope with poor image quality (i.e., highlighting landmarks that might be difficult to see) and

low update rates (providing predictive information). For example van Erp, Korteling, and Kappé (1995) found that overlaying a grid on the camera image improved awareness of camera and UAV movements. While a static camera image was presented, the grid lines moved across the image to help the operator understand the real-time movement of the UAV. Calhoun et al. (2005) described another more advanced system for augmentation of camera imagery – the SmartCam3D System (SCS). This combines camera imagery with a computer-generated 3D representation of what the camera should be capturing. SCS has a number of useful functions such as picture-in-picture (PIP) presentation, where real video footage is surrounded by synthetic graphics to effectively increase the FOV (see Figure 4). Successful integration of the system into a UAV ground control station has already occurred, although there are still issues to address with regard to design, implementation, and integration (Calhoun et al., 2005).

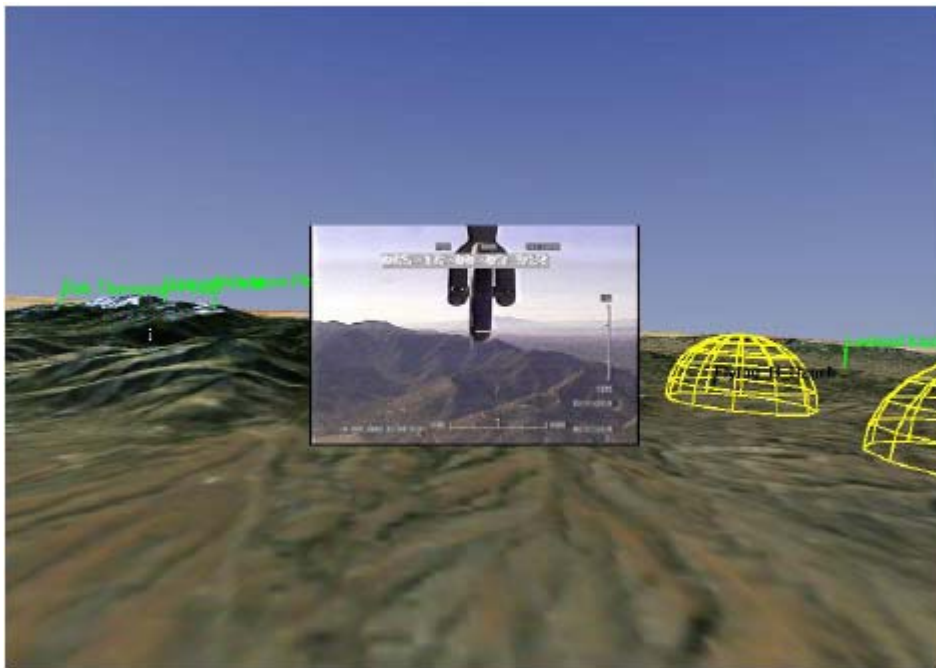


Figure 4. The picture-in-picture (PIP) concept. Real video footage is surrounded by synthetic imagery, to provide context (taken from Calhoun et al, 2005).

While there is little UAV-specific information pertaining to augmented reality displays, there is a large body of research on augmented reality and other displays on the mixed reality continuum (e.g., Barfield & Furness, 1995; Milgram, Takemura, Utsumi, & Kishino, 1994). Augmented displays have also been used extensively in teleoperation activities such as robot arm operations aboard space shuttles, and for medical and scientific visualisation (e.g., Barfield & Furness; Betting, Feldmar, Ayache, & Devernay, 1995; Grimson et al., 1995; Kim, Schenker, Bejczy, Leake, & Ollendorf, 1993). Investigation of a number human factors issues relating to the use of augmented reality displays in UAV ground stations is still required. The appropriate level of augmentation for optimal interpretation of UAV imagery needs to be determined, and any risk of operators placing too much trust in the augmented imagery must be taken into account (McCarley & Wickens, 2005). The possibility of cognitive tunnelling (excessive focus on an element of synthetic vision

symbology leading to neglect of the sensor images), and clutter must also be considered (Calhoun et al., 2005; Yeh & Wickens, 2001).

3.4 Situational Awareness

Maintenance of pilot SA is paramount in aviation safety. For operation of highly autonomous UAVs a number of factors combine to produce a situation where it can be extremely difficult to maintain SA:

1. Display design that may not be optimal for maintenance of SA (see sections 1.1 and 1.2);
2. The separation of the pilot from the aircraft, resulting in sensory isolation (see section 1.2);
3. Data link delays, dropouts, and poor image quality from onboard sensors (see section 1.3), and;
4. Long periods of monitoring a highly automated system, such that the operator may feel 'out of the loop'.

Williams (2004) noted the importance of understanding the paradigm shift from traditional piloting to commanding an aircraft indirectly through pre-programmed routes, menu selections and dedicated knobs, to determination of UAV display requirements. With this move toward supervisory roles for operators will come new kinds of failures brought about by a lack of vigilance and over-trust in automation (van Erp, 2000). The use of a well-designed HMI may be seen as one element of a strategy to reduce the likelihood of failures. A well-designed HMI should work well both in times of high workload and low workload and ensure a smooth transition during hand-overs (Mouloua, Gilson, Kring, and Hancock, 2001).

Along with the methods for HMI improvement discussed in previous sections, Mouloua Gilson & Hancock, (2003), and Mouloua, Gilson, Kring, et al. (2001) have suggested that SA may be improved by representation of the system and environment at multiple levels. Providing information that allows operators to conceptualise the system in different ways is useful as people reason about systems at different levels of abstraction depending on their goals and intentions (Rasmussen, 1986). Presenting information about the environment inside and outside of the UAV, and the processes underlying automated actions are examples of how to increase awareness of the aircraft status (Mouloua, Gilson, Kring, et al.).

The approaches for dealing with problems leading to reduced SA that have been discussed here would, in many cases, require costly display modifications that would be difficult implement, and that require further study. Although it is essential to examine the impact that HMI deficiencies will have on operator SA, this is not the only area to consider. For instance, crew selection processes should be aimed at finding those that are best suited to maintaining vigilance over long periods, and training operators to use specific techniques for maintaining SA on long and potentially boring monitoring tasks is also of importance (Durlach, 2004; Toet & Hogervorst, 2004). Additionally, the maximum length of time that an operator can safely monitor the UAV status, and ideal rest periods need to be determined.

3.5 Summary

Various human factors issues have been raised that are relevant to the HMI of highly autonomous HALE UAV systems. Despite the aircraft being unmanned, it is important to remember that humans are still heavily involved in the operation of UAVs, and that in some cases separation of the operator from the aircraft can intensify human factors difficulties, as the operator experiences sensory isolation from the aircraft and its environment, and may feel 'out of the loop'.

An advanced HMI for control of UAVs should aim to increase operator SA, effectively manage workload, and improve overall UAV system performance (Wilson, 2002). Achieving such a level of effectiveness will require the incorporation of measures aimed at alleviation or mitigating the potential human factors problems that have been outlined here. Such measures include using established display design principles as a guide to improve displays and controls, using multimodal displays to overcome sensory isolation, and installing augmented graphics displays to aid in the interpretation of on-board sensor images. Future research should examine these issues and interface issues that arise in situations where control of multiple UAVs is required.

4. Air Traffic Management & Crewing Issues

This section deals with a range of issues relating to the air traffic management and crewing of UAVs. Such issues include the hand-over of control during long endurance flight, the effect of variable total loop time on response to air traffic control instruction, and the nature of autonomous behaviour that should be adopted by the automated system should a loss of ground-to-air communications occur. An understanding of team member roles is important for future examination of the effectiveness of team processes. The issue of operator certification is also important. High levels of automation may reduce the need for operators with high levels of expertise, resulting in potential savings on training investment. However, this possibility requires examination.

4.1 Air Traffic Management Procedures

4.1.1 Hand-over procedures

McCarley & Wickens (2005) make the point that long endurance UAV flight will require transfer between operators. This transfer may take three forms. Firstly, control may be passed from one ground control element (GCE) to another. Secondly, control may be passed from one crew of operators to another within the same GCE. Thirdly, control may be passed between operators within the same crew. Transfer of control is argued to be a critical and high-workload phase of UAV operation, as procedures for hand-over may be complex and require precision, placing additional demands on human operators.

Accidents have occurred during transfer of control between GCEs. Williams (2004) describes a particular mishap involving a Predator, in which procedures for hand-over were not completed in the prescribed order, resulting in the engine and stability augmentation unit being switched off and the subsequent crash of the aircraft. In more highly automated UAV systems, where SA may be degraded (Tvaryanas, 2004), hand-over procedures that take pilot awareness into account prior to hand-over appear to be most useful.

In terms of the hand-over of UAV control, two areas of future research are vital to ensuring the safe operation of large, highly automated UAVs (McCarley & Wickens, 2005). These are the development of formal procedures for hand-over of UAV control between teams of operators, and the further development of systems and displays to ensure that operators are adequately informed of system status.

4.1.2 Communication processes and data link delays

The introduction of and reliance on data link and digital voice for communication introduces additional problems for UAV operation and ATC. Digital voice communication technology offers some advantages over traditional analog technology including high reliability and ease of maintenance and use. However, digital voice communications also have important drawbacks, such as propagation delay, which in turn increases the numbers of step-ons. Step-ons represent instances in which a pilot or controller interferes with another's transmission causing the interference of both transmissions. Time lags in communication during time-critical operations such as ATC, which are unpredictable in terms of the controller's expectations, impact negatively on working methods, strategies, and performance of ATC (Rantanen, McCarley, & Xu, 2004).

Delays in the data link potentially add as many as several seconds to the communication loop between UAV operators and ATC (McCarley & Wickens, 2005). The duration of these delays is variable and therefore presents predictive difficulty for the system operators. The compounding effect of delays in data link and digital communication may result in reduced predictability of response characteristics, and this may create difficulty for ATC and proximal aircraft.

Co-ordination of crew activities through communication has been recognized as crucial to success in UAV operations such as location and identification of surface targets (Draper, Geiselman, Lu, Roe, & Haas, 2000). In such scenarios, success is heavily dependent on efficient communication between team members. However, communication may be hampered by separation from the aircraft, the separation of crew-members in the GCE, and frame-of-reference differences between earth-referenced locations and sensor-referenced locations.

Communication delays may affect changes in team dynamics, impacting the nature of command and control. Kiekel, Gorman & Cooke (2004) examined speech flow during a five minute communication channel glitch in a simulated UAV task between the mission controller and air vehicle operator (AVO). All communication was mediated via headsets. The mission team compensated for the glitch via the mission controller communicating to

the payload operator who then communicated with the AVO. The authors observed that the glitch weakened co-location effects, and produced behaviour more analogous to that of distributed teams. The glitch was also observed to change the dynamic between air vehicle operator and payload operator, with the co-located team becoming more air vehicle operator dominated and payload operator reactive.

Examination of team communication content may also deliver insights into team process. Team process is considered to mediate team member inputs and team performance. Content analysis methods such as Latent Semantic Analysis have been applied to synthetic Predator crew communication tasks (Gorman, Foltz, Kiekel, Martin, & Cooke, 2003). It was suggested that average task relevance of team communications and task-relevant topic shifting are related to UAV team performance. Team communication and cognition, when treated in this way, may lead to greater appreciation for what represents optimal team communication, and may help derive hypotheses regarding causal factors of effective team performance. This in turn will advance understanding on how best to train effective UAV teams.

4.2 Crewing

An argument for the introduction of UAV systems is the cost savings in human lives and labour. Increases in the automation of UAV systems raises questions regarding the number of people required and the skills that are appropriate to undertake UAV crew duties. The main focus of attention regarding UAV operation and qualifications has centred on qualification requirements for UAV pilots.

4.2.1 Crew member roles

Crewing arrangements for UAVs varies according to the role of the specific system. For reconnaissance role UAVs, crewing chiefly comprises an AVO and mission payload operator. Given that large, endurance-oriented UAVs are used for reconnaissance and surveillance activities that require the extended use of a number of onboard sensors, crews for the Predator and Global Hawk can be large, with highly defined roles for crew members.

In the case of Predator (Weeks, 2000) the AVO serves as an internal pilot controlling the aircraft from take-off to landing through an interface that includes computer screens and throttle, stick and rudder pedals or with an additional Launch and Recovery Element (LRE). While in autonomous mode, the AVO is required to monitor flight information. The AVO will often control the vehicle manually during times of data collection. Typically four AVOs are required for each long endurance mission, two for each shift. Generally, the most senior AVO is given the role of mission commander (MC), although this role may fall to a non-aviation officer such as an intelligence officer. A sensor operator (SO) is responsible for optimal sensor selection and target acquisition. A synthetic aperture radar (SAR) operator is responsible for SAR image capture and target identification. The primary data exploitation, mission planning, and communications (DEMPC) operator identifies target sequence and best collection method and passes the target coordinates to and directs the SO. A secondary DEMPC operator is responsible for image capture,

annotation and mission reporting. The minimum crew size is three: AVO/MC, DEMPC and SO.

The Global Hawk aircraft is controlled from the LRE and the MCE (Weeks, 2000). The minimum crew of the MCE will consist of an MC, command and control operator (CCO), mission planner (MP), communications operator, imagery quality control technician and maintenance technician. The style of control for Global Hawk is *management by consent* (refer to Fig 1). Flight takes place according to the flight plans preprogrammed by the MP during mission planning. The CCO is responsible for flight following (i.e., monitoring conformity with the flight plan), fault diagnosis, and mission monitoring and will intervene only under exceptional circumstances. In these cases, the CCO can select one of a range of automated flight options, such as *abort*, *return to base*, *go to waypoint x*, *change heading* and *change altitude*. Intervention in programmed flight requires a pilot's knowledge of basic flight dynamics and knowledge of the specific flight dynamics of Global Hawk.

Literature on crewing and role delineation in long endurance UAVs and its lack of emphasis on group processes indicates that technology has been the main driver for the development of crew roles. UAVs are at least partly conceptualised as labour saving platforms, and the refinement of team operations may be an important mechanism through which labour may be reduced, whilst maintaining safe and operationally effective platforms.

4.2.2 Operator certification

To date, the literature on operator training requirements for UAV operation appears split on the issue of whether operators require high level pilot qualifications, depending on the nature of operation and the size of the system.

Schreiber, Lyon, Martin, and Confer (2002) assessed groups of subjects' ability to learn and perform manoeuvres during flight of a Predator. The participant groupings were experienced Predator pilots, experienced USAF pilots selected to fly Predator, recent USAF early jet training students, successful single-engine instrument private pilot licence candidates, and untrained university students. The study was limited to stick-and-rudder skills, and did not measure other operationally relevant factors such as communication skills, command experience, knowledge of combat operations or familiarity with airspace management particularly in war zones. Schreiber, et al. found that prior flight experience reduced the number of trials required to become proficient at manoeuvring and landing the Predator simulator. Prior flight experience was also demonstrated to improve *time-on-target* for a reconnaissance task, involving sensor-on-target maintenance.

The transition to a Predator AVO role can be difficult for pilots of manned aircraft, even those with experience at flying many different types of aircraft. In a study conducted by Ryder, Scolaro, and Stokes (2001), experienced pilots training to operate the Predator described the aircraft as slow and unresponsive, and reported difficulties with determining when to adjust pitch, power or speed. The AVO has access to imagery taken from a camera on the nose of the aircraft. The FOV of this imagery is about 30 degrees, providing significantly less information than is available to the pilots of manned aircraft.

Also, displays such as the tracker map display may be under-utilised, as they do not have counterparts on manned aircraft. Other display configurations, such as those used in the HUD are unique to the Predator (Ryder, et al.). There is therefore the potential for negative training transfer for experienced pilots transitioning to flying UAVs such as Predator.

Operators of highly automated UAVs may not need to be rated pilots. Barnes, Knapp, Tillman, Walters, and Velicki (2000) made use of the US Army's Job Assessment Software System (JASS) to examine important cognitive skills for UAV operators and external pilots. The skills and abilities rated by JASS fall into six categories: communication, speed-loaded, reasoning, visual, auditory and psychomotor. They found that operators supplied ratings on the UAV operator, external pilot, and payload operator roles. Operator flight-related scores were not rated as demanding on any of the skill types, except communication. The external pilot role was rated as more difficult on all skill types, especially psychomotor skills.

Weeks (2000) argued that considerations about pilot qualification might not be constrained by experience and skills in flying; rather, that part of this consideration should take into account the nature of military organisations. That is, pilots who are commissioned officers (or officers with comparable standing) may be in the best position to fill this type of role as these personnel are best placed to influence doctrine and policy related to technology. Pilots may have greater metacognitive resources to bring to the UAV operator context than non-pilot operators. Metacognition is referred to as *thinking about thinking* (Kraiger, Ford, & Salas, 1993), and involves the use of evaluative cognition preceding or following goal-directed cognitive activity. In the context of UAV operation, experienced pilots may be more skilled at detecting when their interpretation of information from available displays is consistent with their mental model of the aircraft's behaviour. While it is possible that others, for example, navigators, may have similar metacognitive skills, this has not been addressed in the literature on UAV operation.

4.3 Summary

This section highlighted a number of major issues including hand-over between crew members, communication delays and their impact on team dynamics, the different roles of HALE UAV crew members, and the issue of whether operators should be rated pilots. Further investigation of these issues is warranted, given the paucity of research in this area. For example, more extensive examination of team communication and cognition using methods such as Latent Semantic Analysis would be beneficial, as would assessment of the metacognitive skills of different operator classes to help determine their suitability for UAV operation.

5. Conclusion

This document has highlighted a number of areas of risk in the operation of highly autonomous HALE UAV aircraft. These were discussed under the sections on automation, the human-machine interface, and air traffic management and crewing. Aircraft

automation can help to circumvent human error on high risk tasks, reduce operator workload and permit the reallocation of UAV operators' physical and cognitive resources to higher level functions. However, for automation to be most useful, a number of human issues need to be considered. Such issues may include the SA of the operators, and their ability to monitor the automated system over extended periods. It is important to be aware that automating various functions does not eliminate human input, but rather changes the role played by the human. This introduces additional issues that must be addressed if optimal performance is to be achieved. Such issues may relate to the potential for error during mission planning or the failure to detect system faults due to an inappropriate level of trust in the automated system. The operator needs to be kept informed of the activity of the system, and must be capable of acting in instances where automation fails.

The development of a HMI with a high degree of usability is particularly important for UAVs because the operators and aircraft are not co-located. The separation of operator and aircraft means that there is an absence of sensory cues that may otherwise allow the operators to develop a greater awareness of aircraft status and the flight environment. An advanced HMI for control of UAVs should aim to increase operator SA, facilitate workload management, and improve overall UAV system performance (Wilson, 2002). Achieving a high level of effectiveness will require the incorporation of measures that mitigate a range of potential human factors issues. These measures may include using established display design principles to improve the utility of displays and controls, using multimodal displays to overcome sensory isolation, and installing augmented graphics displays to aid interpretation of on-board sensor images.

A number of issues relating to the hand-over of control between crew members, communications delays and their impact on team dynamics must be addressed if operational effectiveness is to be optimised. Further research should also address the selection and training of crew members, the different roles they may play, and the team processes involved in the operation of HALE UAVs.

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Appendix A: Annotated Bibliography

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Assessed the importance of using rated aviators for AVO and external pilot positions in the case of the Hunter UAV.

Calhoun, G. L., Draper, M. H., Abernathy, M. F., Patzek, M., & Delgado, F. (2005). Synthetic vision system for improving unmanned aerial vehicle operator situation awareness. *Proceedings of SPIE: Enhanced and Synthetic Vision*, 5802, 219-230.

A discussion of the synthetic vision system Smartcam3D (SCS) and its value at increasing situational awareness for UAV operations. SCS combines video footage obtained from onboard sensors with a computer generated 3-D representation of the scene that the camera should be viewing. Text and symbology overlays are also used to highlight key elements in the visual scene. The extra information provided is particularly useful in instances of data link delays and dropouts, and poor visibility. Predicted operational benefits include faster target acquisition and assessment, more targets serviced, and reduced potential for collateral damage. Related human factors issues are discussed.

Calhoun, G. L., Fontejon, J. V., Draper, M. H., Ruff, H. A., & Guilfoos, B. J. (2004). Tactile versus aural redundant alert cues for UAV control applications. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 137-141.

An investigation of the utility of tactile alerts (vibration on wrists) as a substitute for aural alerts or a redundant cue to visual alerts. Eighteen participants responded to critical events alerted with aural or tactile redundant cues, while performing multiple tasks in a simulated UAV control station. Performance was significantly higher when aural or tactile alerts were presented, although there were no significant performance differences between aural and tactile cue conditions, suggesting that tactile cues could be used as a substitute for aural alerts, or that either tactile or aural cues could be successfully used as a redundant cue to visual cues. Trends in performance data and subjective ratings suggested that tactile alerts might be especially advantageous in noisy conditions.

Draper, M. H., Ruff, H. A., Repperger, D. W., & Lu, L. G. (2000). Multi-sensory interface concepts supporting turbulence detection by UAV controllers. *Proceedings of the First Human Performance, Situational Awareness and Automation Conference*, 107-112.

Examines the utility of a multisensory interface for *stick and throttle* type UAVs that alerts the operator to the onset of sudden wind turbulence during a simulated landing task. Ten rated pilots participated in the study. Alert cues were either visual, visual/haptic, visual/auditory, or visual/haptic/auditory. The haptic cue consisted of vibration applied to the control stick at the onset of turbulence, while the visual cue was a single *beep* at the

onset of turbulence. Results indicated that landing accuracy was significantly improved on trials incorporating haptic feedback. Workload ratings were significantly lower and subjective SA ratings were significantly higher when either haptic and/or auditory cues were used. Operators also indicated a preference for the use of redundant, multisensory cues for detection of turbulence.

Draper, M. H., Geiselman, E. E., Lu, L. G., Roe, M. M., Haas, M. W. (2000). Display concepts supporting crew communication of target location in unmanned air vehicles. *Proceedings of the IEA 2000/ HFES 2000 Congress*, 3.85-3.88.

The study evaluated displays designed to expedite transfer of target location information between two UAV operators.

Gawron, V. J. (1998). Human factors issues in the development, evaluation, and operation of uninhabited aerial vehicles. *AUVSI'98*, 431-438.

This paper provides a brief description of a number of UAV human factors issues:

- Data link drop outs
- Maintaining vigilance
- Image analysis
- Control of multiple UAVs
- Target detection, identification, and tracking
- Communication flow
- Take off and landing difficulties
- Vehicle control difficulties
- Inconsistent software
- Team SA
- Undesirable job

The uses of UAVs (military and civilian) are also discussed and a brief summary of the following US military UAVs is given: Dark star, Eagle Eye, Global Hawk, Gnat, Hunter, Outrider, Phoenix, Pioneer, Predator, and Sprite. Consideration of the human factors issues of uninhabited ground vehicles (UGVs) is recommended.

Gorman, J. C., Foltz, P. W., Kiekel, P. A., Martin, M. J., & Cooke, N. J. (2003). Evaluation of latent-semantic analysis-based measures of team communications. *Proceedings of the Human Factor and Ergonomics Society 47th Annual Meeting*, 424-428.

Latent-Semantic Analysis was employed to develop methods to assess communications content between team members in a Predator UAV simulation.

Gunn, D. V., Nelson, W. T., Bolia, R. S., Warm, J. S., Schumsky, D. A., & Corcoran, K. J. (2002). Target acquisition with UAVs: Vigilance displays and advanced cueing interfaces. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 1541-1545.

An experiment was conducted to examine performance at a vigilance task using advanced cueing displays. Sixteen naïve observers participated in the mixed design study, with two

warning display event rates (slow, fast), two warning display formats (sensory – where a change in digit size indicated a hostile aircraft, and cognitive – where threats were indicated by odd-even or even-odd digit pairings), and four cueing interfaces (no cueing, visual, spatial-audio, and haptic). Analysis of results revealed that the sensory display format resulted in more threat detections with fewer false alarms, faster acquisition times, and imposed a lighter workload than the cognitive display format. Visual, spatial audio, and haptic cueing interfaces enhanced the speed of target acquisition compared to no cueing, and each to a similar degree. Overall, results suggested that a sensory display format and use of advanced cuing interfaces may be useful in future UAV systems and that the type of interface may be interchangeable.

Kiekel, P. A., Gorman, J. C., Cooke, N. C. (2004). Measuring speech flow of co-located and distributed command and control teams during a communication channel glitch. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 683-687.

Automatic measures of low-level team communication flow were used to assess high-level constructs of team cognition. During a mission containing a five minute communication one-way channel cut, all teams communicated more like distributed teams, and team members created alternate pathways to retain information flow.

Lam, T. M., Boschloo, H. W., Mulder, M., van Paassen, M. M., & van der Helm, F. C. T. (2004). Effect of haptic feedback in a trajectory following task with an unmanned aerial vehicle. *IEEE International Conference on Systems, Man and Cybernetics*, 2500-2506.

Presents the results of an experimental evaluation of using haptic feedback to perceive tunnel walls during simulated manual control of a UAV helicopter in a trajectory following task. A tunnel in the sky display was used with the tunnel walls representing environmental constraints. Six participants were asked to fly the helicopter as fast and accurately as possible along the trajectory. In the haptic feedback conditions there was feedback from the sidestick based on either the *parametric risk field* or the *generalized potential field*. Performance was measured by the root mean square of the lateral position error. There was also a condition with no haptic feedback (only visual information). The trajectory level of difficulty was either easy or difficult. It was found that use of the parametric risk field could improve performance significantly over use of visual information only, although there were some concerns over increased workload and limitations on operators' control behaviour. Use of the generalized potential field did not have a significant effect on performance, control, or workload.

McCarley, J. S., & Wickens, C. D. (2005). *Human factors implications of UAVs in the national airspace* (Technical Report AHFD-05-05/FAA-05-01). Savoy, IL: University of Illinois, Aviation Human Factors Division.

Review of safety issues relating to UAVs in US national airspace and elsewhere.

Mouloua, M., Gilson, R., Daskarolis-Kring, E., Kring, J., & Hancock, P. (2001). Ergonomics of UAV/UCAV mission success: Considerations for data link, control, and display issues. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 144-148.

Data link considerations include delays and dropouts and these can impact upon the successful control of UAVs. Using supervisory flight management of onboard automation can reduce the risks associated with data links, as complex tasks would be less susceptible to data transmission delays. Use of predictive graphics displays and sending out an initial UAV to collect data are also discussed as alternative ways of dealing with data link problems. The pros and cons of different levels of automation for control of UAVs are specified and information about the ideal features of controls and displays is given.

Mouloua, M., Gilson, R., & Hancock, P. (2003). Human-centred design of unmanned aerial vehicles. *Ergonomics in Design*, 11, 6-11.

Looks at human factors considerations in the design and use of interfaces and controls for UAVs and unmanned combat aerial vehicles. Issues discussed include:

- The automation design dilemma
- Data-link delays
- Control design
- Cognitive workload limitations
- Information display
- Situation awareness
- Target detection
- Team structure and training

Mouloua, M., Gilson, R., Kring, J., & Hancock, P. (2001). Workload, situation awareness, and teaming issues for UAV/UCAV operations. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 162-165.

Workload Focuses on mental workload and includes a discussion of maintaining vigilance over long periods where the task may be repetitious and dull. Issues surrounding level of automation are discussed.

Situation awareness Providing operators with the capability to conceptualise the system at different levels is specified as a potential aid for increasing SA. The large range of data that can inform UCAV operators (as compared to those in manned aircraft) is discussed.

Teaming Suggests that research is needed to determine optimal UCAV crew size, and issues related to teamwork. Communication of information within or across teams is an area that is discussed, as is handling of abnormal or emergency situations.

Rantanen, E. M., McCarley, J. S. & Xu, X. (2004). Time delays in air traffic control communication loop: Effect on controller performance and workload. *The International Journal of Aviation Psychology*, 14(4), 396-394.

Experimental examination of the impact of digital technology-induced delays on pilot-controller communications on air traffic controllers' performance and workload, manipulated through systemic radio delay and variable pilot delay.

Ryder, J. M., Scolaro, J. A., Stokes, J. M. (2001). An instructional agent for UAV controller training. *UAVs - Sixteenth International Conference*, 3.1-3.11. Bristol, UK: University of Bristol.

Describes the development of an automated agent (EAGLE) that allows simulation to be used as an instructorless intelligent training system. The approach involves the use of an instructional agent, and autonomous software entity that embodies the reasoning of an expert human instructor.

Schreiber, B. T., Lyon D. R., Martin, E. L. & Confer, H. A. (2002). *Impact of prior flight experience on learning Predator UAV operator skills (AFRL- HE-AZ-TR-2002-0026)*. Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Examined a range of subject groups' ability to learn stick and rudder skills associated with manoeuvring a Predator UAV.

Tvaryanas, A. P. (2004). Visual scan patterns during simulated control of an uninhabited aerial vehicle (UAV). *Aviation, Space and Environmental Medicine*, 75, 531-538.

Eye tracking (dwell) measurements were recorded for five instrument rated pilots on usage of primary flight instruments on a simulated UAV (Predator), which made use of moving text box symbology. Pilots failed to increase engine instrument dwells in the absence of non-visual cues of engine performance.

Tvaryanas, A. P., Thompson, B. T., & Constable, S. H. (2005). *U.S. military unmanned aerial vehicle mishaps: Assessment of the role of human factors using HFACS (Technical Report)*. Brooks City-Base, TX: Human Performance Directorate.

This report provided the results of a 10-year cross sectional analysis of human factors in US military UAV mishaps. It was found that 60.2% of the mishaps were human-related. There was also discussion of the various categories (e.g., instrumentation/sensory feedback, latent failures at different levels in the organisation, judgment/decision-making, skill-based) in which these mishaps occurred.

Van Erp, J. B. F. (2000). Controlling unmanned vehicles: The human factors solution. *RTO Meeting Proceedings 44 (RTO-MP-44)*, B8.1-B8.12.

Focuses on the field of tension between needing to optimise human performance, which may require a large capacity data-link, and design criteria that constrain bandwidth. To help resolve this matter two approaches are suggested: 1. Reduce data link pressures by omitting non-critical information, and 2. Use advanced interface design techniques to

overcome the consequences of data link shortcomings. Remote camera control is also covered. The results of various other studies are incorporated.

Weeks, J. L. (2000). *Unmanned aerial vehicle operator qualifications (ARFL-HE-AZ-TR-2000-0002)*. Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Report compares selection criteria for UAV operators across branches of the U.S. and U.K. military.

Williams, K. W. (2004). *A summary of unmanned aircraft accident/ incident data: human factors implications*. DOT/FAA/AM-04/24 Office of Aerospace Medicine, Washington, DC 20591

A review and analysis of UAV accident data conducted to identify important human factors issues across small to large surveillance and reconnaissance aircraft in the US services.

Wilson, J. R. (2002). UAVs and the human factor. *AIAA Aerospace America*, 40, 54-57.

Discusses US military use of UAVs (including Global Hawk and Predator) and associated human factors issues, including UAVs working in teams of aircraft. Describes the activities of AFRL's Synthetic Interface Research for UAV Systems (SIRUS) lab including design and evaluation of the Multimodal Immersive Intelligent Interface for Remote Operation (MIIRO).

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19. ABSTRACT This review of literature outlines the human factors issues associated with the operation of unmanned aerial vehicles (UAVs). In particular, consideration is given to how these issues might be relevant to the acquisition of highly autonomous, high altitude long endurance (HALE) UAVs for maritime patrol and response operations. In a highly automated UAV system optimal mission performance will require the roles of the operator and the automated system to be complementary. Thus factors that may inhibit cooperation between the two are addressed and suggestions made for the mitigation of potential problems. The discussion then turns to the design of the human-machine interface (HMI), providing information on established HMI design principles and issues relating to the separation of the operator from the aircraft. The final section covers the air traffic management procedures for the hand-over of control during flight, data link delays and their impact on team dynamics, the selection and training of crew members, and the delineation of roles for UAV crews.					